Research and Development for Pioneering a New Communications Paradigm with Wide-area Coverage

Shigeru Iwashina, Katsuhiro Shimano, Koichi Takasugi, Kazunori Akabane, and Takashi Saida

Abstract

Research and development at NTT Network Innovation Laboratories aims to establish elemental technologies for next-generation communication networks envisioned under NTT's Innovative Optical and Wireless Network (IOWN) and the 6th-generation mobile communication system (6G). These technologies, which include advanced and high-capacity backbone optical transmission networks and extended coverage of wireless communications, are being developed to support dramatic changes in the information society such as the expansion of remote work due to the COVID-19 pandemic. This article introduces optical/wireless transmission technologies and systemization technologies currently being researched and developed at NTT Network Innovation Laboratories.

Keywords: optical transmission technology, wireless transmission technology, IOWN/6G

1. Introduction

Social activities that enable remote participation have become widespread as reflected by the adoption of remote work as a countermeasure against the COVID-19 pandemic. To support these activities, there are growing expectations for the development of next-generation communication networks envisioned under NTT's Innovative Optical and Wireless Network (IOWN) and the 6th-generation mobile communication system (6G) featuring, for example, advanced and high-capacity backbone optical transmission networks and extended coverage of wireless communications. Research and development (R&D) at NTT Network Innovation Laboratories aims to establish communication technologies that can exploit the physical waves of diverse frequency bands including light, radio, and sound waves and enable long-distance, high-speed, and high-capacity transmission in a wide range of areas including communication media such as optical fiber, water, and air. Researchers at NTT Network Innovation Laboratories understand that their mission is to pioneer a new communications paradigm by achieving the above research targets using scientific knowledge based on physics and mathematics such as that related to electromagnetic wave propagation and light propagation, digital signal processing, and media processing.

As shown in **Fig. 1**, the research scope of NTT Network Innovation Laboratories covers a wide range of areas. Researchers usually dealt with optical fiber and radio wave propagation, but today, the research scope has broadened as far as low-frequency bands, such as sound waves, and research targets have extended beyond air and enclosed spaces, such as optical fiber, to include all types of spaces and media from water to outer space as communication media. Research in underwater acoustic communication targeting water, for example, aims to achieve information transfers beyond the Mbit/s class capable of video transmission. To achieve extreme-high-capacity wireless transmission toward 6G [1], NTT Network Innovation Laboratories is also researching and developing new areas such as orbital angular momentum (OAM)

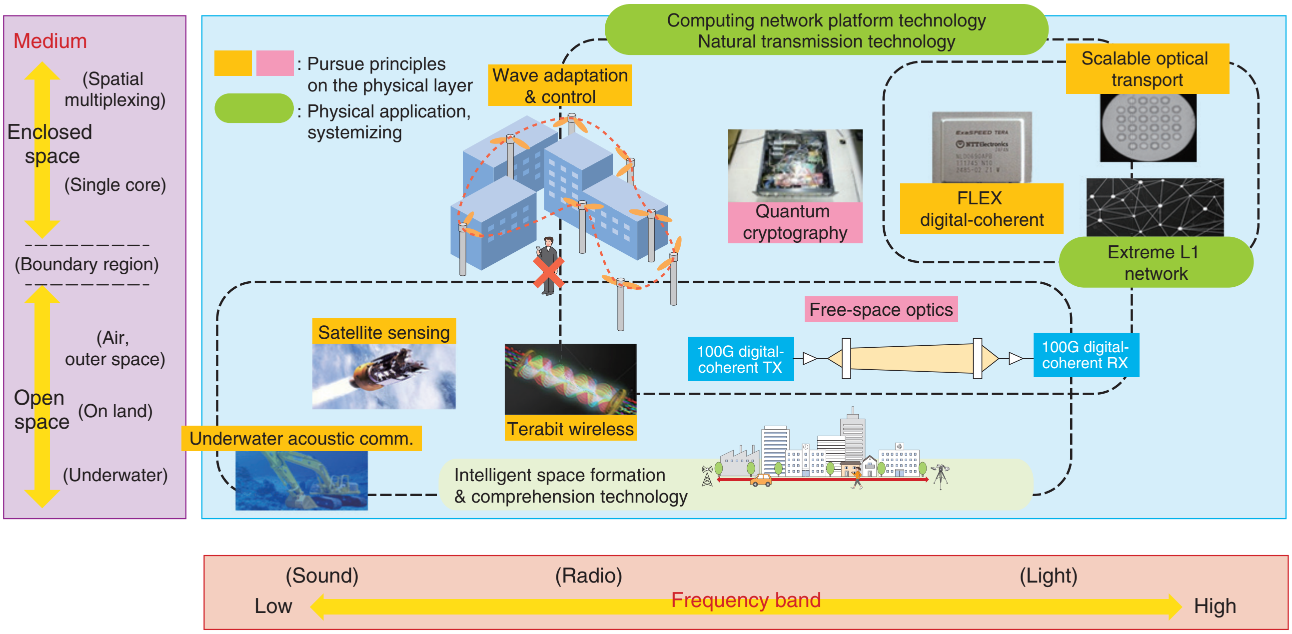


Fig. 1. Research scope of NTT Network Innovation Laboratories toward IOWN/6G.

multiplexing transmission wireless communications, free space optics (FSO) assuming air and outer space as media, and quantum cryptography communications for achieving the ultimate in security.

At NTT Network Innovation Laboratories, we are also engaged in specific R&D toward the development of the All-Photonics Network (APN) [2], which is one of the three main pillars of NTT's IOWN initiative. This includes the R&D of elemental technologies for achieving a next-generation optical communication network that can easily provide high-capacity optical communication paths to a variety of customers as expected of the APN. Specific projects include the development of a low-power digital signal processor (DSP) for achieving 400-Gbit/s-class signal transmission through digital-coherent optical transmission technology, demonstration of bulk extension of the optical amplification bandwidth through wideband optical parametric amplifiers, and the development of technology for automatically setting high-capacity optical communication paths.

The remainder of this article introduces a number of initiatives in cutting-edge technologies undertaken by NTT Network Innovation Laboratories toward IOWN/6G divided into frontier communication technologies, wave propagation technologies, and innovative transport technologies.

2. Frontier communication technologies

An outline of frontier communication technologies is shown in **Fig. 2**. With the aim of achieving cyber-physical systems such as smart cities, we are working on optical-path automatic optimization/control technology for connecting computing resources distributed over a wide area on the IOWN APN and high-speed remote data-transfer technology for achieving high-capacity, low-latency data transfers. These technologies will lead to the establishment of an optical network platform for ultra-wide-area distributed computing. We are also working on natural media processing technology to transmit information on the configuration of physical space in real time with low latency toward ultra-high-presence communication including video and on multimodal wireless environment-comprehension/prediction technologies to predict, set, control, and manage communication quality and the environment through sensing and artificial intelligence (AI). We are also taking up the challenge of establishing secure-transmission technology for envisioning the use of quantum computers.

2.1 Optical network platform for ultra-wide-area distributed computing

At NTT Network Innovation Laboratories, we are developing technology for dynamically connecting

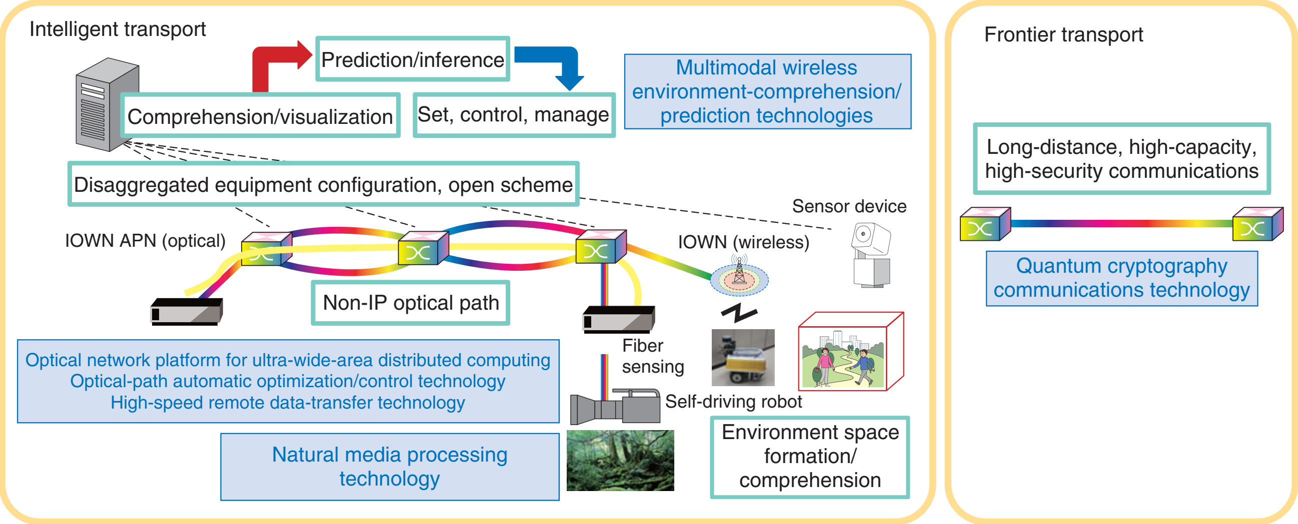


Fig. 2. Outline of frontier communication technologies.

computing resources, such as accelerators and memory devices, distributed over an ultra-wide area on the APN through the optimal design and control of transmission modes and optical paths on the basis of optical characteristics. This technology will enable the construction of optical paths that extract maximum optical transmission performance. Our aim is the establishment of an optical network platform toward ultra-wide-area distributed computing essential to the development of smart cities through high-speed remote data-transfer technology, which will make exclusive use of bandwidth on ultra-long-distance optical paths and synchronize remote memory devices with extreme low latency.

2.2 Natural media processing technology

We are developing spatial reconstruction technology with extreme low latency with a view to ultra-high-presence communication. This will be accomplished by accommodating information on the configuration of physical space in APN optical paths as a time series of high-speed digital signals, enhancing high-speed media transfers with low-latency features to enable long-distance transmissions with extreme low latency, and using lightweight machine learning. Looking to the future, we aim to establish cross-layer AI monitoring technology to collect the input/output of people, things, and the environment across multiple layers and make inferences from those data. Our goal with this technology is to enable automatic optimization even during system operation through state monitoring and detection of anomalies and their causes.

2.3 Multimodal wireless environment-comprehension/prediction technologies

To satisfy a variety of requests for network services to be provided by IOWN, we are developing technologies for using diverse types of physical space information obtained using cameras and sensors for predicting communications quality several seconds into the future and for maintaining high-quality communications at all times through optimal communication means. Our goal is to establish environment-comprehension technology that uses the relationship between physical space information and wireless communication system information to extract the former, such as location information, from the latter.

2.4 Quantum cryptography communications technology

NTT Network Innovation Laboratories is exploring new technology areas based on optical technologies toward long-term innovative contributions to the IOWN initiative. Specifically, we aim to use optical-fiber transmission technology and communication protocol technology to achieve a quantum cryptography communications system that overcomes the limitations in distance and communication speeds in conventional quantum key distribution. We will also endeavor to establish security and transmission technologies for the age of quantum computers.

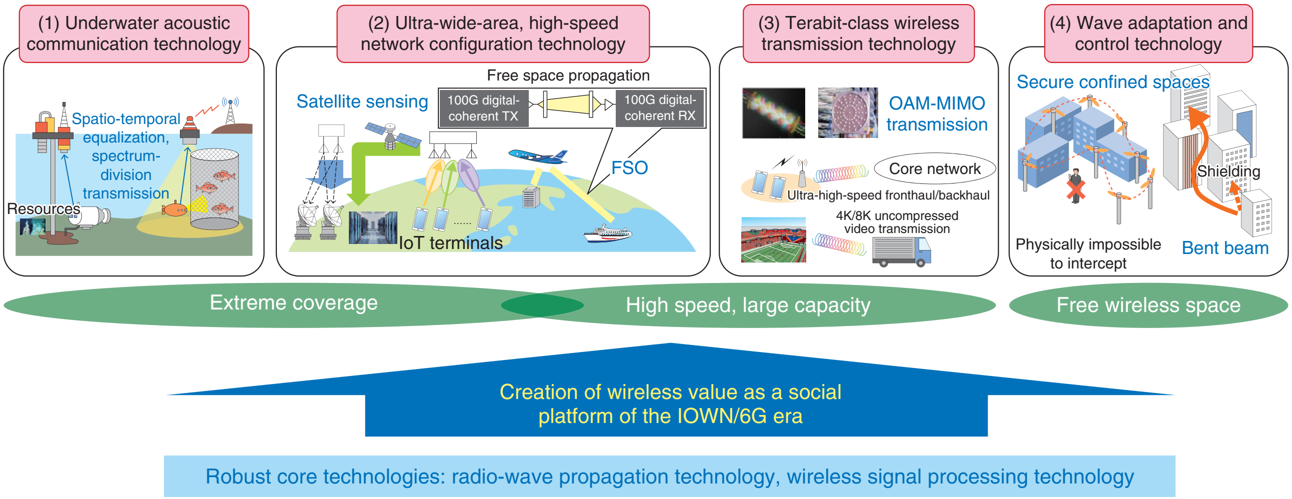


Fig. 3. R&D related to wave propagation technology.

3. Wave propagation technologies

Wireless communications in the IOWN/6G era is expected to have a variety of features. These include extreme coverage extension that includes coverage in the sea and outer space in addition to terrestrial communications, high-speed/high-capacity transmission irrespective of the points being connected, and flexible wireless space formation that confines radio waves to the targeted area, all with the aim of creating new value in wireless communications. At NTT Network Innovation Laboratories, we are working on four key technologies toward the creation of wireless value as a social platform for the IOWN/6G era: (1) underwater acoustic communication technology, (2) ultra-wide-area, high-speed network configuration technology, (3) terabit-class wireless transmission technology, and (4) wave adaptation and control technology (**Fig. 3**).

3.1 Underwater acoustic communication technology

Wireless communication technology based on radio waves capable of high-speed, stable, and long-distance communication has not been established for underwater applications; as a result, unmanned probes and undersea heavy equipment used for resource development on the ocean floor or for port construction typically connect with a support vessel on the surface of the sea using a communication cable 100 m or longer to achieve remote operations [3]. This state of affairs has been a major issue from the viewpoint of work efficiency. We aim to establish Mbit/s-class underwater acoustic communication technology to enable wireless remote control of underwater equipment and devices. This technology will include spatio-temporal equalization technology to compensate for significant waveform distortion of acoustic waves and spectrum-division transmission technology to achieve high speeds through broadband transmission.

3.2 Ultra-wide-area, high-speed network configuration technology

Areas in which people do not live, such as in highly rural and mountainous areas and the open sea, may not have a terrestrial wireless communication infrastructure for economic reasons. Our aim is to achieve ultra-wide-area, high-speed networks in areas where no wireless communication infrastructure has been set up. To this end, we are pursuing satellite Internet of Things (IoT) platform technology [4] to enable the collection of sensor data on a global scale and FSO platform technology to enable 100-Gbit/s-class high-speed communications in areas such as the open sea.

3.3 Terabit-class wireless transmission technology

Terabit-class wireless transmission technology is considered necessary for the fronthaul and backhaul in the IOWN/6G era [5]. We aim to further increase transmission bandwidth and the amount of spatial multiplexing essential to terabit-class wireless transmission through digital signal processing technologies.

These include OAM and line-of-sight multi-input multi-output (MIMO) schemes for achieving spatial multiplexing and high-frequency-band Butler circuit configuration technology for increasing the bandwidth of OAM multiplexed transmission.

3.4 Wave adaptation and control technology

In wireless communications, radio waves tend to spread in all directions even outside the area targeted for communications. This leakage of radio signals outside the intended area results in a drop in confidentiality, increase in interference, and power loss as universal problems in wireless communications. We aim to establish the ultimate in wireless communications by preventing the leakage of radio waves using wave-control techniques. These will include terminal-coordinated, user-centric radio access network technology that links not only base stations but also terminals to form wireless space in an adaptive manner and multi-shape wave-control technology to fully control radio-wave trajectories.

4. Innovative transport technologies

NTT Network Innovation Laboratories is pursuing innovative transport technologies for achieving extreme-high-capacity optical paths as a platform for IOWN. In particular, we are researching and developing digital-coherent optical transmission technology including the development of a low-power, 1-Tbit/s-class DSP for optical communications as well as opto-electronic integration technology to link light and electricity and analog and digital circuits. We are also working on innovative Layer 1 networking technology to generate new value for users and operators and pioneering elemental technologies toward a dramatically new user experience (UX) in the APN. With the aim of efficiently accommodating massive amounts of traffic in the future, we have taken on the development of innovative extreme-high-capacity transmission technology with a 10-Pbit/s-class throughput per node, which is enabled by scalable optical transport platform technology driving the development of optical signal processing technology.

4.1 FLEX digital-coherent optical transmission platform technology

NTT Network Innovation Laboratories aims to establish FLEX digital-coherent optical transmission platform technology as an elemental technology for economically achieving IOWN (**Fig. 4**). This technology will achieve long-distance and low-power high-capacity optical transmission of the 1-Tbit/s class essential to the construction of the APN. In addition to conventional long-distance transmission oriented to carriers, this technology is also applicable to short-range transmission such as datacenter interconnects. For rapidly expanding application areas, it aims to achieve optimal optical paths by using a digital signal processing function to make flexible changes to the transmission scheme, type of compensation processing, etc. in addition to high-accuracy transmission path monitoring.

4.2 Scalable optical transport platform technology

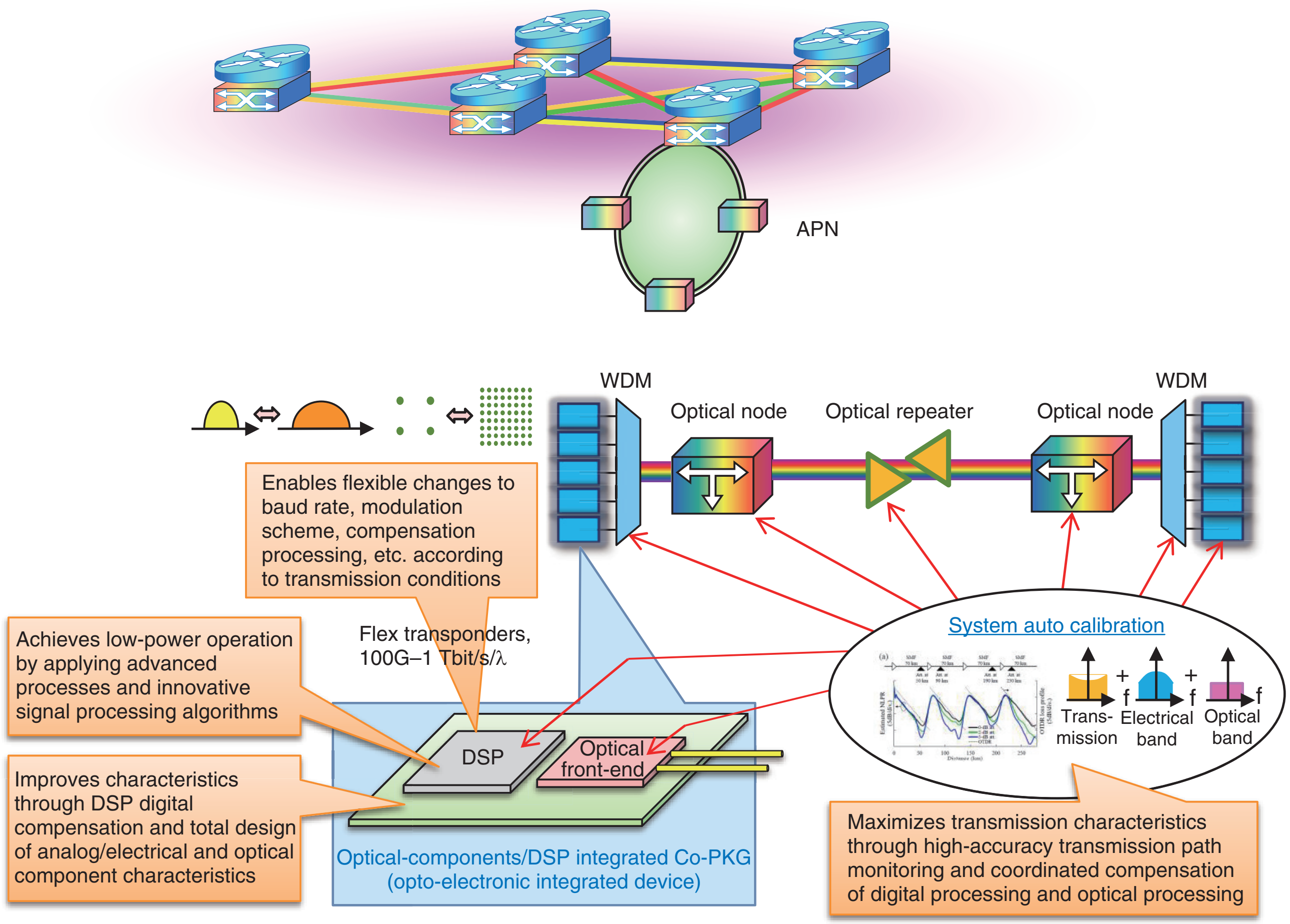
A petabit-class optical network will be needed to accommodate the massive volume of communications traffic that will be generated by the expansion of cloud services and further penetration of smartphones. As part of our efforts to meet this need, we have demonstrated bulk extension of the optical amplification bandwidth through wideband optical parametric amplification repeaters [6] and undertaken the development of large-capacity spatial-multiplexing transmission technology using core multiplexing and mode multiplexing [7]. Our aim is to pioneer innovative extreme-high-capacity transmission technology and optical signal processing technology to make this possible and establish scalable optical network platform technology of the 1-Pbit/s class per link.

4.3 Extreme Layer 1 networking technology

We aim to generate value for users and operators through Layer 1 networking and contribute to the implementation of the APN by demonstrating specific use cases together with collaborators. To this end, we are developing elemental technology for dramatically enhancing the UX through instantaneous creation of a Layer 1 communication path to any location and elemental technology for revolutionizing operations by enabling network configuration changes to be made at will through Layer 1 switching without interrupting communications. Through these technical developments, we are exploring a variety of use cases such as demonstrating that remote e-sports matches can be conducted fairly even at the professional level by using Layer 1 communication path delay/adjustment technology [8].

5. Conclusion

This article outlined cutting-edge technologies now



Enables flexible changes to baud rate, modulation scheme, compensation processing, etc. according to transmission conditions

Achieves low-power operation by applying advanced processes and innovative signal processing algorithms

Improves characteristics through DSP digital compensation and total design of analog/electrical and optical component characteristics

Maximizes transmission characteristics through high-accuracy transmission path monitoring and coordinated compensation of digital processing and optical processing

WDM: wavelength division multiplexing

Fig. 4. Digital-coherent optical transmission platform technology for rollout in APN.

being pursued by NTT Network Innovation Laboratories toward IOWN/6G. Going forward, our goal is to achieve early establishment of various elemental technologies toward the deployment of IOWN/6G scheduled for 2030 by collaborating with business partners and specialists in a variety of industrial fields.

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He received a B.E. and M.E. from Tokyo Institute of Technology in 1993 and 1995. Since joining NTT DOCOMO in 1995, he has been engaged in the development of core network equipment for mobile communications systems, network architecture research, and network virtualization research. After conducting R&D on mobile communications systems ranging from 2G to 5G, he was assigned to the R&D Planning Department of NTT in July 2019 to promote R&D collaboration with partners to develop and implement NTT's IOWN initiative. He has been in his current position since July 2020.

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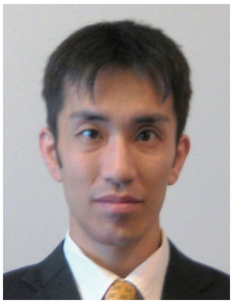

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